A Method for Assessing Occupational Pesticide Exposures of Farmworkers

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Background *The health of farmworkers as related to pesticide exposure is of concern but assessing exposures for epidemiologic studies requires different techniques than approaches used for studies of industrial workers.*

Methods *A review of the literature identified possible factors that affect exposure intensity. A model was developed to estimate an exposure score. Exposures in the literature were estimated using the model and compared to the measurements in the literature.*

Results *Three studies were found with information appropriate for evaluation of the model. There was a statistical difference between the means of the scores corresponding to above and below the median of the measurements. The correlation coefficient between the scores and the measurements from the literature was 0.77.*

Conclusions *Although the evaluation was limited, the model appeared to work well, but more testing is needed. More research is also needed to increase understanding of what affects the exposures of these workers.* Am. J. Ind. Med. 40:561–570, 2001.
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INTRODUCTION

The health of farmworkers and the effect of work on their health have recently become topics of interest [Zahm and Blair, 2001, this issue]. Work can be the source of a number of health problems, including skin and ergonomic conditions, but one of the biggest concerns is disease related to pesticide exposure. Epidemiological studies investigating the effect of pesticide exposures can use a number of surrogates to represent exposure. Two surrogates are ever/never worked as a farmworker, and to investigate exposure–response relationships, number of years worked as a farmworker. These surrogates are appealing because they are simple and straightforward. However, they suffer from a number of limitations [Stewart and Herrick, 1991] that can result in considerable misclassification regarding exposure status. Their use could miss a real association with a disease.

To reduce this possible misclassification, an assessment method has been developed to rank study subjects by their possible occupational pesticide exposure. We first describe the assessment procedures used in studies of populations working in industry and the limitations of these procedures for assessing exposures to farmworkers. We then discuss findings in the literature that can assist in understanding the sources of exposures to farmworkers. An assessment method that can be used in the evaluation of exposure–response relationships and a limited validation effort to determine how well the method predicted measured exposures are presented. Finally, areas where more research is needed are described. The paper addresses only the issue of exposure and not the dose received by a person.

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METHODS

Background on Exposure Assessment Procedures

The general concepts of assessing exposures in studies that investigate populations working in industry are well accepted. Depending on the design of the epidemiological study (cohort or population-based case-control) different assessment approaches are taken. Generally, for either design, information on the job title, type of industry, dates the job was held, and sometimes other descriptive data (e.g., activities or self-reported exposures), are collected for each study subject. For each job, a level of intensity is estimated. An estimate of the probability of exposure may also be made if it is uncertain whether the job entails exposure to the chemical of interest. Sometimes investigators identify the confidence they have in their estimates.

For intensity, measurements from a work place are used when available to estimate in measurement units (e.g., mg/m^3), the average daily exposure intensity of individual subjects or jobs. In most studies, measurement data are so limited that exposure intensities are estimated for jobs and all subjects having the same job are assigned the same exposure intensity. Where measurements are lacking on particular study subjects or jobs in the study, investigators modify available measurements on similar groups in the same or similar workplace to reflect the differences between the measured and unmeasured groups.

If no measurements are available from the workplace, measurement data can often be obtained from the published literature. Lacking measurement data, quantitative (e.g., 1–10) or semi-quantitative (low, medium, or high) unitless scores are often developed to reflect differences in exposure conditions and, therefore, exposure intensities of the study subjects or jobs. Investigators develop the scores by implicitly or explicitly putting weights on factors that affect exposures; these are called determinants of exposure. Either approach, i.e., using measurements or developing scores, allows the exploration of exposure-response relationships.

Estimating probability of exposure in a cohort study is typically not done because usually enough information is available about the workplace to be confident about the likelihood of exposure. In case-control studies, however, because lifetime work histories are often collected from the study subjects or proxy respondents, little information is available on each specific job. Self-reported job information may be ambiguous with regards to specific exposures, and usually it is not feasible to contact the work sites to collect better information, because of the large number of work sites identified with the study subjects. To compensate for these limitations, estimates are often made of the probability that an exposure occurred to an individual. In addition, because the evaluation of intensity and probability is made on varying quality of data, investigators sometimes identify their confidence in the estimates.

Assignments of both probability and confidence can be used to reduce misclassification in an epidemiological analysis by stratifying the population by these variables. For example, an exposure–response analysis can be conducted across the different exposure levels that includes all subjects (i.e., all probabilities and all levels of confidence). Other exposure–response analyses can be conducted across the different exposure levels that include only subjects with higher probabilities or confidence. If an exposure–response relationship is seen with all subjects, it should be stronger when only subjects with higher probability or confidence are included in the analysis because there is less misclassification.

Exposure assessment for farmworkers is much more difficult than for most industrial workers. Farmworkers do not know what pesticides have been applied to the crops they work and workers generally are employed at many more work sites over their lifetime than subjects in industry [Zahm et al., 2001, this issue]. Also, little is known about what factors influence farmworkers' exposures. Finally, the usefulness of the published literature on pesticide exposure measurements on these workers is limited due to lack of consistent measurement strategies and reported information. Nonetheless, the literature was reviewed to provide insight on how exposures might be assessed in this population.

Estimating the Probability of Pesticide Exposures to Farmworkers

The first step in evaluating exposures among farmworkers in an epidemiologic study is to identify the pesticides applied to the crops worked. Because information is usually not available on the pesticides used at specific work sites it is useful to estimate the probability of exposure. An approach has been described for estimating the probability of exposure to pesticides based on the job information provided by the worker (crop/task/date/location) and on state or federal survey data on pesticide use [Ward et al., 2001, this issue].

Estimating the Intensity of Pesticide Exposures Among Farmworkers

Definition of Intensity of Exposure

For those individuals having some probability of exposure, the intensity of exposure should be estimated to allow separation of those individuals with possibly high risk (because of high exposure) from those with possible low risk (because of low exposure). In most epidemiological studies, intensity is estimated for airborne exposures only, but it actually should incorporate exposures from all routes. In measurement studies, two routes are typically measured for farmworkers: dermal and respiratory. Most studies of farmworkers that have measured both exposures have found that respiratory exposures contribute about 1% of the total exposure [Spear et al., 1977; Popendorf et al., 1979; Davis et al., 1982, 1983; Everhart and Holt, 1982; Herman et al., 1985]; this route is therefore not discussed in this review. An additional route of pesticide exposure for farmworkers is likely to be ingestion; one source of ingested pesticides is from pesticide adherence to soil or to other particulates inhaled by the worker. The size of these particles can be such that they may be deposited in the nasopharynx during inhalation and then swallowed [Popendorf and Leffingwell, 1982]. For most workers, however, the soil is not likely to be a major source of exposure unless the soil becomes airborne [Zweig et al., 1985]. Another source of exposure may be through the ingestion in the fields of food contaminated with pesticides that have been transferred from unwashed hands. No information is available on this source of exposure and so ingestion is not further discussed here.

Using Determinants of Exposure in the Estimation of Intensity

To identify the determinants that affect farmworkers' exposure intensity, it was found that the evaluation of those determinants has been inconsistent and often appears to be incidental to the study. Few studies have evaluated the effect of determinants under controlled conditions. The crops, tasks, pesticides applied, and measurement methods have all varied (Table I). The number of locations on the body measured for dermal exposure ranged from 2 to 15. Information on quality control procedures was often lacking. Some investigators have reported the results of statistical tests and others have just reported anecdotal information.

The determinant that has been investigated has been the dislodgeable foliar residue (DFR). DFR is the concentration of pesticide on leaves or the fruit that can be transferred to the skin of an individual coming into contact with that plant. This determinant may be one of the most important for farmworkers' exposures because it is likely to be the predominant source of exposure to the hands, which are often the largest contributors to the overall exposure. Two studies have found a good to excellent correlation between the DFR and pesticide concentration on the hands [Maitlen et al., 1982; Nigg et al., 1984]. DFR has also been moderately correlated with measurements of pesticides on clothing or on exposed skin [Zweig et al., 1983, 1985; Nigg et al., 1984, McCurdy et al., 1994; De Cock et al., 1998a], and with estimated whole body dose [Popendorf et al., 1979; Popendorf, 1980; Nigg et al., 1984]. Pesticide residue in soil is probably a less important source of exposure, except for tasks that generate considerable dust, such as weeding [Zweig et al., 1985]. The amount of pesticide applied affects exposures [Zweig et al., 1983] and is likely to be related to DFR.

Information on the importance of other exposure determinants is limited. For example, the half-life of a pesticide may be important [Maitlen et al., 1982; Davis et al., 1983; Tielemans et al., 1999]. The half-life of the pesticide, defined here as the time it takes for the pesticide to decrease in concentration by one-half, can be thought of as the persistence of the pesticide on the vegetation or in the soil. It describes the rate of change in the concentration of the pesticide on the crop and may be different for leaves and fruit of the same plant. It is likely to be determined by both characteristics of the pesticide and other factors such as meteorological conditions (e.g., moisture in the fields [Herman et al., 1985], and humidity and dew on the crop [Zweig et al.,1983, 1985]). The half-life varies by pesticide and can be substantial. For example, pesticide residues have been found on grasses up to 20 weeks after having been sprayed with endrin [Wolfe et al., 1963], and carbaryl has been measured on the hands of farmworkers working a crop 38 days after pesticide spraying [Maitlen et al., 1982]. Because many pesticides have half-lives on the order of a few weeks, it is likely that farmworkers often enter pesticide-treated fields within the time that the pesticide is still present on the crop in substantial amounts.

The task being performed also affects the exposure intensity. For example, the exposure intensity of field weeding was 9–10 times higher than that that of field harvesting [Zweig et al., 1985]. The exposure intensities from orchard harvesting, pruning, and bending/tying up were about half that resulting from orchard thinning [De Cock et al., 1998b]. Characteristics of the crop, such as height, may also affect the exposure intensity [Zweig et al., 1985]. Other determinants of exposure that have been suggested include pounds picked [Zweig et al.,1983; Nigg et al., 1984; Fenske et al., 1989], duration of the exposure [Fenske et al., 1989], and handedness [Zweig et al., 1983, Herman et al., 1985].

Work practices may also affect exposure intensity. Water for washing has often not been available in the fields. In one report 95% of farmworkers who smoked reported doing so without washing beforehand, and half reported eating without washing [Ciesielski et al., 1994]. Even if they do wash, however, the skin may still be contaminated. Two studies conducted on other types of pesticide workers found pesticides on the skin 1–3 days after exposure [Wolfe et al., 1961; Ringenberg, 1988]. In addition, work surfaces of other types of pesticide workers have been found to be contaminated with pesticides [Frank et al., 1985, Sanderson et al., 1995], so it is likely that any equipment used by farmworkers (e.g., crates, bags, hoes, ladders, etc.) are also

TABLE I. Characteristics of Published Studies on Farmworkers

Study	Crop	Task[a]	Pesticide	Application Rate (lb. active ingredient/acre)	Time to re-entry after application	Method, body/hand[b]	Under/outside clothing (U/O)	No. body locations	Quality control results reported (yes/no)
Orchard crops									
Fenske et al., 1999	Apples	Th	Azinphosmethyl	2	NR	-/G,R,W	0	2	no
Maitlen et al., 1982	Apples	Th	Carbaryl	2–4	0–52 d	P/R	0	8	yes
Davis et al., 1983	Apples	Th	Azinphosmethyl	1	1–9 d	P/G,R	0	4	yes
Davis et al., 1982	Apples	Th	Phosalone	NR[c]	24–48 hr	P/G	0	8	yes
Popendorf, 1980	Citrus	H	Parathion, Methidathion, Dioxathion	2–8	22–61 d	P/-	0	9	no
Nigg et al., 1984	Oranges	H	Chlorobenzilate	0.51	1 d	P/R	U,O	14	no
Spear et al., 1977	Oranges	H	Ethyl parathion	2–8	14, 21, 25 d	P, C/-	0	15	no
Fenske et al., 1989	Peaches	H	Captan	2	NR	-/G,R	U,O	2	yes
Popendorf et al., 1979	Peaches	H	Phosalone	4–5	3–24 d	P/G,P	U,O	12	no
McCurdy et al., 1994	Peaches	H, Pr, Th	Azinphosmethyl	NR	14, 74 d	W,C/R	U,O	6	no
De Cock et al., 1998a	Apples, pears, plums, others	H, Th, Pru, BT	Captan	NR	NR	P/R	U,O	8	yes
Tielemans et al., 1999	Fruit—not specified	H	Captan, Tolylfluanid	0.28–0.75	0–35 d	P/P,G	0	5	no
Field Crops									
Zweig et al., 1983	Strawberries	H	Dicofol; Benomyl, Captan	NR	4 d	P/G	0	4	yes
Everhart and Holt, 1982	Strawberries	H	Benomyl	1	24 hr	P/G	0	10	yes
Winterlin et al., 1984	Strawberries	H	Captan	2.2	3 d	P/G	U, O	10	yes
Zweig et al., 1985	Strawberries, Blueberries	H,W	Captan, Carbaryl, Vinclozin, Methiocarb	0.49–1.3	3–33 d			2–10	yes
Herman et al., 1985	Tobacco	H	Maleic Hydrazide	1.1	3 d	P/R	0	9	no
Munn et al., 1985	Onions	H	Toxaphene, Ethyl parathion, Methyl parathion, Malathion	NR	6–7 wk	-/G	0	2	no

[a]BT, bending/tying; H, harvesting; Pk, picking; Pr, propping; Pru, pruning; Th, thinning; W, weeding.
[b]P, professional farmworker, V, volunteer; C, clothing; G, glove; P, patch; R, rinse; W, wipe.
[c]NR, not reported.

contaminated. Forty percent of farmworkers did not always launder clothing before wearing it again [Ciesielski et al., 1994]. If a worker has substantial exposure from work, exposures received from contamination in the house may be at least an order of magnitude lower than work exposures [De Cock et al., 1998a] and so may be less important for many workers.

Assessment of Farmworkers' Exposure Intensity

Generally it is assumed that the specific agent of interest in a pesticide-related job is the active ingredient of the pesticide. Other ingredients are present in a pesticide, however, that may cause an adverse health effect. These are called inert ingredients, not because they are not harmful, but because they do not act as a pesticide. Information on inert ingredients, however, is not required from manufacturers of pesticides, so that information on their identification and frequency of occurrence is rarely available. In addition, some pesticides are converted in the field into another chemical and it may be this converted product, rather than the actual active ingredient, that is the agent causing the disease. For example, some pesticides are converted to an oxon analogue in the field [Spear et al., 1977; Popendorf et al., 1979]. Whether other pesticides convert to other substances and what the toxicologic importance of the converted products is is not known.

The data available for estimating the intensity of exposure are likely to be limited for any particular epidemiologic study and it is unlikely that any measurements of study subjects will exist. The limitations of the measurement data in the published literature (Table I) suggest that it is currently more appropriate to develop unitless exposure scores rather than to estimate the intensity of exposure in specific measurement units. The literature was used, however, to identify exposure determinants and to determine the relative weights that should be assigned.

As indicated above, the most established determinant in the literature is DFR. It is not feasible, however, to measure the DFR for a large number of farmworkers and it is impossible to measure past exposures. To overcome this problem, the amount of pesticide applied could be considered a surrogate for DFR. The amount applied is dependent on the particular pesticide (its concentration and formulation), the crop, the amount of infestation, the meteorological conditions, and personal preference of the farm owner/operator. Further complicating this process, however, is the fact that farmworkers often do not know this information and that contacting the farm owner/operator is not feasible due to the large number of work sites. Thus, of the variables that are likely to affect the amount of pesticide applied only identification of the crop and the location can be easily made by the farmworker [Zahm et al., 2001, this issue].

Although the amount of pesticide applied is likely to vary, the best surrogate of DFR that is currently available is the recommended application rate (RAR). Using recommended application rates to estimate DFR is appealing because the rates can be readily obtained for a specific crop and state (information obtained from the farm worker) and the pesticide (obtained from the published literature [Ward et al., 2001, this issue]. Although the recommended application rates may be modified by the farm owner/operator, this practice is probably not widespread because less pesticide than the recommended rate could result in the farm owner/operator losing his/her crop. Applying more pesticide than the recommended amount would be costly and could result in higher residues on the crop. Historical data on the actual average application rates for specific pesticide/crop combinations are available in the pesticide use surveys from the 1990s [US Department of Agriculture] and in a few of the earlier surveys [Haydu, 1981; Webb, 1981; McDowell et al., 1982; Parks, 1983; Ferguson, 1984].

Using application rates relative estimates of differences in exposure can be obtained for the same crop and pesticide. The amount of pesticide on the crop, however, does not remain constant over time. The half-life (H-L) provides a relative indication of pesticide loss from the crop and is available for some pesticides from the published literature [Extoxnet, 2000]. From the RAR and H-L then, it is possible to develop a relative exposure score that should serve as a reasonable surrogate for DFR.

After reviewing the literature to determine the range of pesticide application rates and half-lives, recommended application rates and the half-lives of pesticides were grouped into four categories (≤ 1, > 1–2, > 2–4, and > 4 lb of active ingredient/acre sprayed and ≤ 1, > 1–2, > 2–10, and > 10 days, respectively). Weights of 0.75, 1.5, 3, and 6 for the application rate and 0.75, 1.5, 6, and 15 for the half-life (roughly corresponding to midpoints) were used in the development of the relative exposure score. The appropriate recommended application rate weight was multiplied by the appropriate half-life weight to obtain the relative exposure score for a given crop and pesticide. This score was used to rank a crop/pesticide combination by its relative exposure intensity for each farmworker.

This relative exposure score was constant, however, for each crop/pesticide. Weighting this score further by task allowed further refinement of the method. Only three studies were found that estimated exposure levels by task. Two used the same pesticide (captan) [Zweig et al. 1985; De Cock, 1998a,b], but the application rate was available only for one [Zweig et al., 1985]. The third study presented medians, not means, and was therefore not considered appropriate for inclusion [McCurdy et al., 1994]. Using only the first study for captan [Zweig et al., 1985], the exposure intensity was normalized for the amount of pesticide applied. In that

TABLE II. Determinants of Exposure

Determinant	Exposure	Comments
DFR[a]	Hands	$r = 0.99$ [Maitlen et al., 1982]
DFR	Hands, body, estimated whole body	$r = 0.99$ [Nigg et al., 1984]
DFR	Hands, forearms	Ratios of DFR for two pesticides was 6.1. Ratio of pesticides on hands and forearms was 7.2 [Zweig et al., 1983]
DFR	Body	$r = 0.90$ [Zweig et al., 1985]
DFR	Body	$r = 0.50–0.57$, reported as a range [McCurdy et al., 1994]
DFR	Hands, wrists, arm, forehead	Statistically significant [De Cock et al., 1998b]
DFR	Estimated whole body	Graphical representation showed body exposure increased with DFR. [Popendorf et al., 1979]
DFR	Estimated whole body	$r^2 = 0.75$ (Popendorf, 1980)
Amount pesticide applied	Hands and forearms	$4\times$ amount applied resulted in $7.2\times$ exposure on skin [Zweig et al, 1983]
Days post application	Hands	Decreased as time increased [Maitlen et al., 1982]
Days post application	Hands, body	Graphical representation showed hand, body exposure decreased with number of days after application [Tielemans et al., 1999]
Days post application	Dermal other than hands	No significant differences over days [Davis et al., 1983]
Moisture	Body	Exposure twice as high for wet crop as dry [Herman et al., 1985]
Morning dew/humidity	Hands and forearms	Higher ($1.8\times$) dermal exposures on day with higher humidity and morning dew [Zweig et al., 1985]
Time of day	Hands and forearms	60% higher exposure in morning (statistically significant), believed caused by dew on foliage [Zweig et al., 1985]
Task	Body	Dermal exposures for weeding $9–10\times$ higher than for harvesting [Zweig et al., 1985].
Task	Body	Thinning $2\times$ higher than harvesting, pruning, bending/tying up [De Cock et al., 1998a]
Task	Body (face, neck, hand socks, shirt)	Harvesting $>$ thinning $>$ propping [McCurdy et al., 1994]
Crop	Body	Strawberry harvesters' exposure to hands and forearms (crop low to ground) vs. blueberry harvesters' exposure distributed to total body (crop taller) [Zweig et al., 1985]
Crates harvested per hour	Hands and forearms	$r = 0.81$ [Zweig et al, 1983]
Boxes harvested	Estimated whole body	$r = 0.41$, $r = 0.72$, $r = 0.76$ for three separate days of harvesting [Nigg et al., 1984]
Buckets harvested per hour	Hands	$r = 0.58–0.69$, reported as a range [Fenske et al., 1989]
Time worked	Hands	$R = 0.41–0.48$, reported as a range [Fenske et al., 1989]
Handedness	Hands, forearms	[Zweig et al., 1983]
Handedness	Chest	[Herman et al., 1985]
Age	Hands	Adult subjects 30% higher hand exposure than youths (authors speculated due to higher work rate) [Munn et al., 1985]
Field worked	Hands	Significant difference [Munn et al., 1985]
Gender	Hands	Men 20% higher hand exposure than women [Munn et al., 1985]
Gender	Body (face, neck, forearms, hands)	No significant differences [Davis et al., 1982]

[a]DFR, dislodgeable foliar residue.

study the mean of strawberry weeders' measurements was 94 mg/h and that for harvesters was 8.9 mg/h [Zweig et al., 1985]. Because 4 lb of pesticide/acre was applied, the weights assigned to these two tasks were 23 lb (94/4) and 2 lb (8.9/4). Duration of the task (h/day) also affects exposures and will vary for study subjects. Because the measurements were in units of mg/h, duration (Dur) was also included in the model while estimating exposure intensities of study subjects to reflect the different numbers of hours study subjects may work.

Another determinant of exposure is the type of clothing worn, and this factor was also incorporated to further refine the model. Farmworkers generally do not wear special protective clothing. Even normal clothing can provide protection [Stewart et al., 1999], however, and wearing different types of clothing should result in differing reductions of exposure. The degree of protection can be described as a protection factor (PF), which can be calculated by taking the inverse of the reduction that occurred in the exposure level. Four levels of protection were assigned: (1) did not wear gloves and wore a short-sleeved shirt or short pants (0% reduction or $PF = 1$); (2) wore a long-sleeved shirt and pants, but no gloves (estimated to result in a 20% reduction or $PF = 1.25$ ($1/.8 = 1.25$)); (3) wore gloves but wore a short-sleeved shirt or shorts (30% reduction or $PF = 1.4$); (4) wore a long-sleeved shirt, long pants, and gloves (estimated to result in a 50% reduction, or $PF = 2$) [Spear et al., 1977; Popendorf et al., 1979; Herman et al., 1985; Zweig et al., 1985; Batel and Hinz, 1988]. Information on other determinants is believed to be too scanty to rely upon at the present time. The final relative exposure score then was calculated as

$$\text{Relative exposure score} = \frac{\text{RAR} \times \text{H-L} \times \text{Task} \times \text{Dur}}{\text{PF}}.$$

The method developed an intensity score for a single pesticide/crop/task combination. In studies of chronic disease such as cancer, however, it is important to estimate lifetime exposures. A lifetime estimate of exposure to a pesticide can be estimated by multiplying the relative exposure score by the number of days spent at each job accumulated across all jobs. While conducting an epidemiological study of chronic disease, if changes occurred in exposure intensity, it is important to quantify changes in exposure to develop accurate lifetime exposure estimates. For farmworkers, perhaps the most important changes over time have been the changes in the frequency, and type of pesticide used [Osteen and Szmedra, 1989]. Regulation of re-entry intervals, which occurred in the early 1970s, may also have reduced exposure levels, although the major impact of this regulation may not have been significant until many years later and it is probably still ignored by some farm owner/operators. This change is probably only important for pesticides with half-lives of less than a few days. Investigators should consider applying a decade weight to the ranking of workers to reflect these changes.

While estimating exposures based on differing qualities of information it is useful to assign a confidence in the estimates. An approach to estimate the confidence in the probability estimates has been described [Ward et al., 2001]. For the intensity estimates a confidence score could be assigned using the following criteria: a score of 4 (high confidence) would indicate the information on the crop and task worked by the farmworker was available. In addition, the RAR and H-L for this pesticide and crop and measurement information on this task and crop was available. Scores of 3 (medium high confidence) and 2 (medium low confidence) indicate crop and task information on the farmworker is available. A score of 3, however, indicates either that, (1) the RAR and H-L were not available for that specific pesticide and crop and had to be estimated using data from a similar pesticide or crop; or (2) measurement information was not available on the task and crop and had to be estimated using data for a similar crop and task. A score of 2 indicates that the RAR, H-L, and measurement data for the pesticide, crop, and task were not available and that information on a similar pesticide, crop, and task was used in the development of the estimate. A score of 1 (low confidence) would indicate that the information on the crop and task was not available for the farmworker or that it was but no extrapolation could be made from similar pesticides, crops, and tasks. In this case, the intensity assigned could be the mean score across all jobs in the study.

To determine how well this model estimated actual exposures one would ideally take measurements of farmworkers performing their tasks and compare the measurements to the estimates derived from the model. This was not possible for this paper, so the published literature was reviewed to identify studies that contained the necessary information for the model. Scores for the amount applied, the half-life of the pesticide, the task measured, and the clothing worn by the study subjects were assigned and the relative exposure score calculated (duration was not relevant because the measurements were reported in mg/h). The median was used to categorize the measurement data (<5 and ≥ 5 mg/h). The relative exposure score categories were compared to the scores using a *t*-test. The Spearman correlation coefficient was also calculated to evaluate how well the individual scores ranked the study measurement means.

RESULTS

Only three studies were found with six unique crop/pesticide exposure scenarios in the literature [Zweig et al., 1983, 1985; Everhart and Holt, 1982] (Table III). The five pesticides evaluated were captan, benomyl, carbaryl, vinclozin and methiocarb, with half-lives of 4 to >20 days. Application rates varied between <1–4 lb/acre. The clothing of the study subjects varied only by the type of shirt worn (short or long-sleeved). Although they all used gloves, the gloves were used as the measurement device and so were not considered as being protective. The studies only covered field harvesting so that task did not influence the scores. The measured exposure levels ranged from 0.3–39 mg/h.

The mean values corresponding to below and above the median of the measurement values were 23.3 (standard deviation (SD) = 5.5) and 6.0 (SD = 1.7). This difference was statistically significant ($P > 0.05$). The correlation coefficient between the scores and the measurements was 0.77.

DISCUSSION

A model was developed to assess exposure of farm-workers to pesticides using determinants of exposure thought to be reasonable based on the current literature. It is a simple, practical method that utilizes fairly easily obtainable information. The results of the limited validation effort suggest that further evaluation of this approach would be worthwhile.

It was a pleasant surprise that the model performed so well. The studies used in the evaluation measured different locations on the body (number of locations ranged from 2 to 15) with different measurement methods (Table I). There was only limited information to identify determinants of exposure and to estimate weights for the model. The task did not contribute to the difference among the studies and the protection factor made only a minimal contribution (weight of 1 or 2). The performance in part may have been influenced by the fact that the same literature that was used to develop the model parameters was used to evaluate the methods' performance. The scenarios that could be assessed were also limited (i.e., harvesting only wearing long-sleeved shirt and long pants), so that it is not clear whether other scenarios (e.g., thinning, pruning, other types of protective equipment) would produce the same results.

For estimating dermal exposure of applicators the general assumption has been made that the specific type of pesticide is not important in the estimation process; rather it is the mechanism of the contaminant generation that is important. In the case of applicators this mechanism is predominantly aerosolization of the pesticide by the spray equipment [van Hemmen, 1993]. This mechanism affects the droplet size, which is the crucial determinant for estimating dermal exposures. Under this assumption, measurement results can be applied to all applicators applying under the same conditions (i.e., the same application rate, duration, etc.), regardless of the pesticide. We used this same assumption when reviewing the literature for exposure determinants and their weights, developing the model, and validating the estimates. It is not clear, however, whether the same assumption holds when the exposure mechanism is not spraying but transfer from foliage or uptake from soil.

In addition to cumulative exposure, the relative exposure level estimates derived from this method can be used to create several exposure metrics for epidemiological analyses. Other exposure analyses could include evaluating study subjects by their highest score, by the number of days above a particular score and by the average score over each subject's lifetime. Each of these analyses evaluate subjects by their level of exposure, but the analyses can also incorporate the estimates of probability and the confidence in the estimates [Ward et al., 2001, this issue]. If two sets of confidence are developed (for intensity and probability), a single confidence value could be derived by summing or

TABLE III. Estimation of Exposure Levels

Study	Pesticide	Crop/task	RAR score	H-L score	Task	PF	Exposure score	Mean exposure (mg/h) (GSD)[a]
Zweig et al., 1983	Captan	Strawberry harvesting	3[b]	6[c]	2	1.25	29	39 (1.6)
Zweig et al., 1983	Benomyl	Strawberry harvesting	0.75[b]	15	2	1.25	18	5.9 (2.2)
Everhart and Holt, 1982	Benomyl	Strawberry harvesting	0.75[d]	15	2	1	23	5.9 (1.5)
Zweig et al., 1985	Carbaryl	Strawberry harvesting	0.75[c]	6[c]	2	1.25	7	1.9
Zweig et al., 1985	Vinclozin	Strawberry harvesting	0.75[c]	6[c]	2	1.25	7	0.3
Zweig et al., 1985	Methiocarb	Blueberry harvesting	1.5[c]	1.5[c]	2	1.25	4	2.9

[a]GSD, geometric standard deviation. Where no GSD indicated, authors provided means without GSDs.
[b]Zweig et al., 1983.
[c]Zweig et al., 1985.
[d]Everhart and Holt, 1982.
[e]http://ace.orst.edu/cgi-bin/mfs/01/pips/benomyl.htm?8#mfs

multiplying the two levels of confidence and dividing the values into tertiles or quartiles to assign confidence levels of 1–3 or 1–4, respectively. Both the estimates of probability and of confidence could then be used to define groups of subjects with increasingly accurate exposure estimates.

Determinants of exposure were used here to estimate relative differences in intensity of exposure. They were selected not only for their likely importance in predicting exposure but also for the likely ability of farmworkers to describe them. Thus, they can be used to identify what questions to ask of study subjects. If the method is valid and subjects can answer the questions on determinants of exposure, the exposure assessment becomes much more efficient and is likely to be more accurate.

Besides further validation of the model and the subjects' ability to describe the determinants, further research is needed before a significant improvement in the evaluation of farmworkers' pesticide-related disease is likely. First, a better understanding of the determinants of exposure is crucial to developing better estimates of the probability and level of exposure. More information on the persistence of pesticides on fruit and foliage is needed. There are many tasks and crops other than those in the current literature that farmworkers typically work, for which exposures have not been measured [Zahm et al., 2001, this issue]. The ability of the clothing material to prevent penetrance of the major chemical classes of pesticides (e.g., organophosphates and carbamates) would also be very useful. It is suggested that these determinants be the initial focus for more research. Identification of the inert materials in pesticides should be made available. Systematic investigation should be made into whether pesticides are converted into other products, the conditions of this conversion and the toxicologic importance of these converted products. The contribution of ingestion of pesticides from eating contaminated food needs quantification. Finally, the model was based on the assumption used in studies of applicators that measurement results will be similar, regardless of the pesticide, when application conditions are the same. Whether this assumption that the type of pesticide is not important holds when the exposure mechanism is from transfer of pesticides through deposition on foliage or from soil needs investigation.

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